PRACTITIONERS' FORUM

Innovation and Competitiveness: A Review

JOHN CLARK & KEN GUY

ABSTRACT *Increasing interest has been shown by governments in maintaining the competitiveness of their economies by the use of policies designed to encourage advances in science and technology, and the adoption of new techniques by industry. This paper is the result of a literature review and a survey of researchers on the concepts of innovation and competitiveness, the relationships between them and the efficiency of policies to promote them. Those policies are considered in the context of alternative economic perspectives, as is the (rather limited) empirical evidence available. Conclusions are drawn on the current state of the art of innovation policy research.*

Introduction

This paper comprises a summary of research and policy thinking on the relationships between innovation and competitiveness. The literature on this topic is of course vast, and a comprehensive treatment is impossible. It is not, in any case, the intention here to produce an encyclopaedic work, even if that were feasible with the time and resources available. Rather, the objective is to produce a short, readable overview of the whole field, to enable policy-makers and other interested non-specialists to obtain a broad appreciation of the current state of the art. We have tried to identify the most important literature references in each of the relevant areas, so that the reader can obtain more detail as required.

Our approach has been to collect and summarize identified key articles, to discuss the area with some leading academics, and to survey some 500 active researchers and sponsors of research with a request for information on the work covered by their organizations and for their choice of important material. Inevitably, the choice of work to be included in this report reflects our biases on the important facets of the innovation/competitiveness issue, and we may well have accidentally overlooked some central activities in the area. Nevertheless, we hope that the review will prove useful as an initial guide to the literature.

The Concepts of Competitiveness and Innovation

Industrial policy and technological development are linked via the concepts of innovation and competitiveness and the relationship between them. Before examining these linkages, however, we need to clarify what we mean by 'competitiveness' and 'innovation'. In this section, we first review micro- and macro-level definitions of competitiveness and related

J. Clark and K. Guy are at Technopolis Ltd, 3 Pavilion Buildings, Brighton BN1 1EE, UK. Tel: 01273 204320; Fax: 01273 747299; E-mail: ken.guy@technopolis.co.uk.

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determinants, together with commentary on the measurement of competitiveness. Similarly, we define innovation processes, innovation networks and so-called systems of innovation before considering some measures of technological change and innovative behaviour. Armed with these definitions and metrics, we then explore current understanding of the relationship between innovation and competitiveness.

Competitiveness

Major recent reviews on the subject of competitiveness include Porter, OECD and Teece.[1] At the micro (company) level, competitiveness is generally understood to refer to the ability of a firm to increase in size, market share and profitability. In traditional economic theory, comparative costs of production determine relative competitiveness at firm level—the way to become more competitive is to produce more cheaply: for example, by finding ways to reduce labour costs. However, recent studies have consistently pointed to non-price factors as being at least as important, if not more important, underlying determinants of competitiveness.[2]

The range of non-price factors is diverse. They include:

- *Human resource endowments*, such as skills and worker motivation.
- *Technical factors* such as R&D capabilities, and the ability to adapt and use technologies.
- *Managerial and organizational* factors, both internal to the firm and external relationships with other bodies: customers, suppliers, public and private research institutes, and other firms.

These factors determine the ability of a firm to attain and maintain a profitable position in the face of changing technological, economic and social environments. Profitability and survival remain the ultimate indicators of competitiveness.

But these indicators are scarcely relevant at the macro (usually national) level, where the concept of competitiveness, although widely used, is generally considered to be less satisfactory than at the level of the firm, with less consensus on the choice of appropriate indicators. Historically, the most widely used indicators have related to international trade. As in the firm-level case, prices were for a long time generally assumed to be the major determinants of trade performance, a view reconsidered when it was found that falls in export prices in the US and UK, and rises in Japan and Germany, had been associated with increases in export share in the latter two countries.[3] These results prompted interest in the possible importance of non-price factors in national competitiveness.

Further, trade balance has increasingly been seen as not the only, or even the most important, indicator of national competitiveness. Domestic conditions are also stressed. Thus, the US Presidential Commission on Industrial Competitiveness (CIC)[4] defines the competitiveness of a nation as the "degree to which it can, under free and fair market conditions, produce goods and services that meet the test of international markets while simultaneously maintaining and expanding the real income of its citizens".

A recent article by Krugman argues against the concept of competitiveness at the national level altogether. To blame economic ills on a lack of competitiveness with other countries is, he asserts, a convenient smokescreen behind which politicians frequently hide in order to avoid more pertinent but less politically acceptable diagnoses. "The idea that a country's economic fortunes are largely determined by its success on world markets is a hypothesis, not a necessary truth; and as a practical, empirical matter, that hypothesis is flatly wrong. That is, it is simply not the case that the world's leading nations are to any important degree in competition with each other, or that any of their major economic problems can be attributed to failures to compete on world markets".[5]

Krugman puts forward some empirical evidence for the apparent lack of significance of trade performance for living standards in the US, and asserts that the same results hold for the European Community and Japan. "In each case, the growth rate of living standards essentially equals the growth rate of domestic productivity—not productivity relative to competitors, but simply domestic productivity". The world is not as interdependent as some people think, and in any case countries do not compete like corporations—they do not go bankrupt, and international trade is not a zero-sum game. Obsession with national competitiveness is dangerous, and can lead to unnecessary trade conflict.

The Institute for Management Development (IMD), Lausanne, and the World Economic Forum have produced a 'world competitiveness scorecard' ranking 22 OECD countries according to 378 different indicators, aggregated to five factors: internationalization, science and technology, management, infrastructure and people, education and skills. Such a scorecard permits the inclusion of many diverse factors, but there is obvious arbitrariness in which factors to include and how they should be weighted. Modifications have recently been made. In response to criticisms such as those of Krugman, the Forum changed its definition of competition in 1996 to simply "the ability of a country to achieve sustained high rates of growth in GDP per capita" (*The Economist*, June 1996). The 1996 Forum competitiveness index comprises 155 indicators, covering hard statistics and results from surveys based on judgement. Factors such as the openness of markets, low taxes, high savings and investment in human capital are included. The resulting international rankings put European Union (EU) countries generally below the US and Japan in the competitiveness league. We consider the position of the EU later, with respect to both economic position and technological performance.

In conclusion, competitiveness seems best seen as a dynamic, even 'evolutionary', concept; since the 1970s in the US, for example, it has successively been viewed mainly in relation to trade and trade policy, industry policy, technology policy and, most recently, simply in relation to raising living standards.[6] In discussing the relationship between innovation and competitiveness later, we will interpret national 'competitiveness' loosely in terms of factors such as growth, productivity and trade performance, all of which are generally perceived to be important for economic development.

Conditions for Competitiveness

What are the conditions which promote competitiveness, especially at the level of the firm? According to Porter,[7] there are four interdependent, mutually reinforcing attributes of a nation that determine whether or not it provides an environment which enables firms in a particular industry to compete successfully.

- Factor conditions, such as the availability of skilled labour and infrastructure.
- Demand conditions for the goods and services of the industry.
- Related and supporting industries, including the presence of competitive suppliers.
- Firm strategy, structure and rivalry.

Porter describes these factors as those which "individually, and as a system, create the context in which a nation's firms are born and compete". Porter considers that the most important issue of all for competitiveness lies in the pressure that these factors exert on firms to invest and innovate.

Recently, there has been increasing stress on globalization of competition,[8] a term

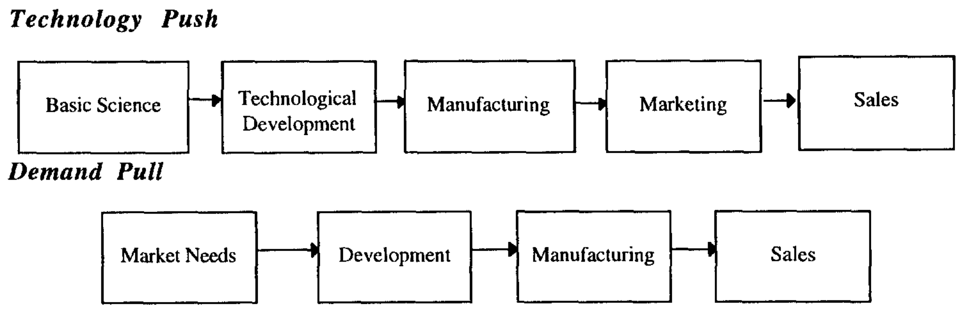

Figure 1. 'Linear' models of innovation.[11]

which highlights the spread of multinational corporations and the internationalization of centres of production. The term thus relates particularly to the increasing direct investment by foreign firms, rather than to increasing trade links between countries.

A further development has been increasing emphasis on path dependency, which points to the importance of history and the development of idiosyncratic features of national economies. This implies the need for policies beyond those traditionally used for national economic policy. Thus, "while the competitiveness of firms will obviously reflect successful management by entrepreneurs or corporate executives, their competitiveness will also stem from country-specific long-term trends in the strength and efficiency of a national economy's productive structure, its technical infrastructure and other externalities on which firms build".[9] The trend in thinking has been towards an increasingly holistic and 'systems' approach, where interactions between 'micro' and 'macro' levels—in particular, the role of the national environment for the competitiveness of the firm—have been given great emphasis.

We now move on to discuss the innovation process, and then the role of that process in stimulating competitiveness.

The Innovation Process

Several reviews and collections of important papers on the economics of innovation and related issues have recently been published.[10] Recent literature on the process of innovation—usually defined as the first commercial application of a new product or process—characteristically begins with a refutation of the so-called 'linear model', the notion that research, followed by development, leads to innovation in a progressive, sequential manner. Two versions of the linear model are often presented (see Figure 1[11]). One, the 'technology push' model, represents innovation as resulting from new ideas in basic science recognized to have commercial potential. The other, 'demand pull', portrays the process as stemming from a market need detected and exploited by the innovator.

The stress is currently on the interactive nature of innovation, with attention being drawn to the importance of various rather complex and diverse feedback processes. Figure 2 indicates the kinds of interactive processes involved. Two major types of interaction with outside bodies can be identified. The first type concerns relationships with customers, suppliers and (where appropriate) collaborators, where monitoring the on-going supply and demand conditions can influence any or all of the development, production and marketing stages, and lead to feedback within those stages. The second set of interactions arises when the technological or production competences within the

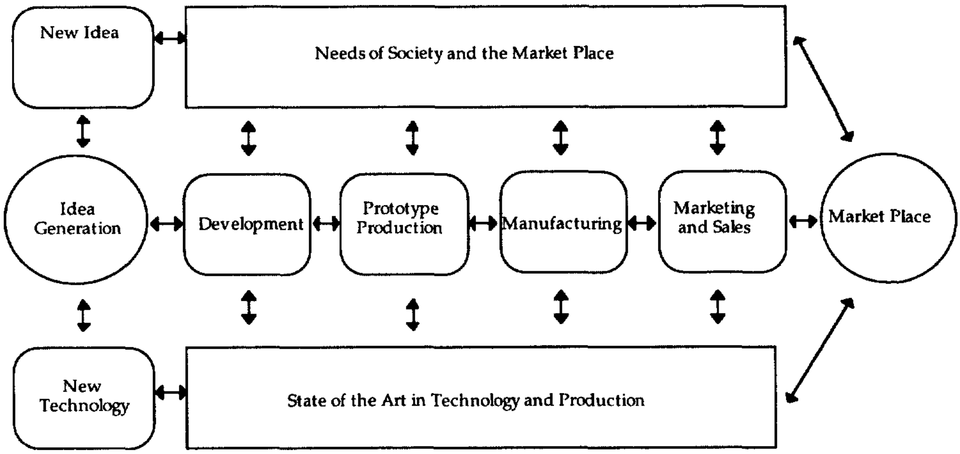

Figure 2. An interactive model.

firm prove inadequate for the task in hand, and appeal to the wider science and technology system is necessary. When a problem is encountered at any stage in the innovation process, engineers will typically first call on existing sources of knowledge. If these prove to be inadequate, the need arises for further research, either internal or external.

Innovation Networks

A central implication of the 'interactive' model is thus the need for close synergy between parts of a firm's R&D system, between that system and the rest of the firm's production system, between the firm and other firms, and between the firm and other private and public institutions. A large literature has appeared over the past 10 years on the issue of 'networks', both formal (such as contractual arrangements for R&D cooperation) and informal (for example, casual exchanges of information between researchers in different firms). Widely used, overlapping concepts in this literature include the following.

- A distinction between 'knowledge' and 'information'. To quote Freeman, "It is not just a question of getting a lot of 'information'; often there is an overload of information. The problem of innovation is to process and convert information from diverse sources into useful knowledge about designing, making and selling new products and processes".[12]
- A distinction between 'codified' and 'uncodified' information, the latter referring to information that is not specified or generally available.
- 'Tacitness', which "refers to those elements of knowledge, insight and so on that individuals have which are ill-defined, uncodified and unpublished, which they themselves cannot fully express and which differ from person to person, but which may to some significant degree be shared by collaborators and colleagues who have a common experience".[13]

Detailed descriptions of different kinds of interactions observed in practice between rival firms, between private and public sector scientists and engineers, between university and industry, and between users and producers, can be found in OECD, Freeman and von Hippel.[14] Commenting on the upsurge of interest in networks, Freeman observes that many studies in the 1970s (such as project SAPPHO in the UK, based on paired comparisons of the attributes of successful and unsuccessful innovations) drew attention to the importance for success of both formal and informal networks, even if the word 'network' was little used at the time. What is new, in his view, is that there has been an increase in collaboration in new generic technologies, especially information technology, and also a qualitative change in the nature of the older networking relationships, which typically have become fuzzier and more flexible.

The Measurement of Technical Change: Science and Technology Indicators

Although written 15 years ago, the review of science and technology indicators by Freeman[15] draws attention to the interactive nature of the R&D system, and to the 'intangible', as well as the 'measurable', features of both inputs and outputs. It traces the development of informal indicators derived by academics and researchers, through to the collection of more comprehensive and standardized national and international statistics.

Reliable standardized statistics on R&D expenditure were first presented in the OECD *Frascati Manual*, published in 1963. Subsequent manuals have continued to represent the most important source of such statistics, only minor improvements having since been made in standards and survey techniques. As a measure of inventive activities, patents represent a rich and well documented source, heavily exploited by academic researchers.[16] Publications, citations and other 'bibliometric' measures of inventive activity are also popular. Patel and Pavitt[17] provide a recent review of these and other measures of R&D activity, pointing out the limitations and deficiencies of each type. They stress particularly the importance of the specific technology and industrial sector in determining the appropriateness of particular indicators.

Indicators of innovative (as opposed to inventive) activity—i.e. indicators referring to the first commercial use of new products and processes, rather than indicators of their first experimental development, such as patents—are not collected routinely by national or international institutions, and are subject to particular problems of definition and measurement. It is obviously absurd, for example, to regard all innovations as equally 'important'. Various classification systems have been proposed: for example, to distinguish between 'incremental', 'radical', 'new technology systems' and 'pervasive generic technologies'.[18] The most appropriate ranking technique needs to be determined by the issue at hand, with due recognition of the dangers inherent in any count of innovations—see Freeman *et al.*,[19] for example, for a discussion of the limitations of this kind of analysis and the risk of confusion between measures of innovation on the one hand and diffusion on the other.

Recent initiatives in measuring innovative activity include data collected in the EU Community Innovation Surveys (CIS). A joint Eurostat and DGXIII initiative, the CIS was developed between 1991 and 1993 on the basis of a common questionnaire drawn from the guidelines suggested in the OECD's *Oslo Manual*. To date, one fairly comprehensive EU-wide survey has been completed. Firms were asked about the following:

- sources of innovation;
- objectives of innovation;
- sales of innovative products as proportions of total sales;
- costs of innovation;
- factors hampering innovation;
- R&D activities;
- impacts of innovation;

- acquisition and transfer of technology.

An evaluation of the CIS by the IKE group in Denmark[20] concluded that the conceptual basis of the survey was well developed, but that the implementation suffered from a lack of harmonization of the questionnaire between countries, uneven sampling frames and variability in the quality of data collected. But it could be argued that such difficulties are inevitable with first attempts at international surveys, and standardization will, it was hoped, improve in later survey rounds. If successful, the results should significantly enlarge the scope for useful analytical work on the innovation/competitiveness issue.

Before turning to that issue, we conclude this section with Table 1,[21] taken from a Science Policy Research Unit report, summarizing the strengths and weaknesses of various science and technology indicators.

The Relationship between Innovation and Competitiveness

We now move on to the central issue of this review, namely the relationship between innovation and competitiveness. In much of the formal research literature, one or more indicator of competitiveness is tested against an innovation indicator for empirical links. Bodies of research include:

- econometric and statistical analyses, investigating, for example, links between R&D expenditures and productivity growth, or between patents and world trade flows;
- economic models, such as 'vintage' models of 'embodied' technology, or (more recently) evolutionary models;
- micro or macro case studies, including retrospective and mixed-mode analyses aimed at exploring the links between R&D, innovation and economic performance, including measurement of impact, at a number of different levels, e.g. firm level, sector level, regional level, national level.

In this section, we first review econometric analyses and attempt to build economic models linking the two variables. Very generally, input/output analyses strongly suggest that technological change is a critical source of economic growth, with high returns to R&D, while neoclassical, vintage and evolutionary models treating technology-related behaviour as the engine of economic growth show a reasonable fit with empirical data. Evolutionary perspectives also suggest that while the need to innovate is not an imperative for the survival of individual firms, innovation is a collective necessity for economic well-being.

We spend little time specifically reviewing case study material, primarily because the profusion of case studies referring to the innovation/competitiveness issue, either directly or indirectly, with reference to particular countries, regions, industries, firms, technologies or organizations, is so diverse that summary coverage is practically impossible. Where generalizable results are known to have come from such studies, they are discussed at apposite points in the text. We do note, however, that while no grand theory has emerged which provides a simple picture of the linkages between innovation and competitiveness, the wealth of data contained in this body of literature has thrown enormous light on the intricate and complex factors which do affect innovative behaviour, and its implications for the competitiveness of firms and economic systems.

Later, we present the results of a questionnaire survey which attempted to characterize and map current research efforts in the sphere of innovation and competitiveness. Some of this research was primarily econometric in nature, or focused on the elaboration

Table 1. Strengths and weaknesses of measures of inventive and innovative activities[21]

			Possible levels of comparison			
Measure	**Strengths**	**Weaknesses**	**Country**	**Industry**	**Tech field**	**Firm**
R&D	• Regular and recognised data on main source of technology	• Lacks details (technical fields and specific firms) • Strongly underestimates small firms, design, production engineering, and software	Yes	Yes	No	Yes
Patents	• Regular details and long-term data • Compensates weaknesses of R&D	• Uneven propensity to patent • Misses software	Yes	Yes	Yes	Yes
Significant innovations	• Direct measure output	• Measure of significance • Cost of collection • Misses incremental improvements	No	Yes	No	Yes
Expert judgements	• Direct use of expertise	• Finding independent experts • Judgements beyond expertise	Perhaps	Yes	Yes	No
Product announcements	• Close to commercialisation	• Misses in-house process innovations, and incremental product improvements • Possible manipulation by marketing and public relations	Perhaps	Yes	No	Yes
Technical employees	• Measures tacit knowledge	• Lack of homogeneity of qualifications	No	Yes	Yes	Yes
Actual versus predicted market value	• Tries to measure firms' efficiency in asset exploitation	• Cannot distinguish innovation from other intangible assets, or from monopoly • Difficult to make international comparisons	Perhaps	Yes	No	Yes

of economic models. Much of it was of a 'case study' nature or focused on particular microaspects of the behaviour of innovation systems. All of it illuminates the wealth of effort currently being expended to enhance our understanding of the critical relationships between innovation and competitiveness.

We round off this section with a look at some empirical indicators of innovation and competitiveness in the EU and a discussion of possible linkages.

Econometric, Statistical and Survey Work

The 'typical' model used for econometric estimation relates a measure of economic output to factor inputs such as capital and labour, and possibly to additional factors such as R&D expenditure.

At the macro level, the early work of Solow[22] related national output to capital and labour inputs only. This research demonstrated that growth in these inputs was totally insufficient to account for output growth. The 'residual' factor, representing increases in the productivity of the inputs, accounted for up to one-half of the growth of the US economy, and was generally assumed to be associated with 'technical change' of one sort or another.

Griliches[23] has considered the addition of a further explanatory variable: a weighted sum of past R&D expenditures, where the weights reflect both delays in the effects of recent R&D and declining returns from earlier expenditures. The results present a fairly consistent picture of high rates of return to R&D. Studies of US firms and industries between 1965 and 1984 suggest rates of return of between 20 and 50% per annum for private R&D, roughly twice as high as rates of return on physical investments. At these rates, the fact that firms do not pour considerably more investment into R&D suggests they have a particular disincentive to invest in R&D, perhaps because firms are risk averse and require a higher expected return to higher riskiness, or because they fear that others will benefit from 'spillover' effects (benefits to third parties from R&D in the form of an increasing 'pool' of publicly available knowledge).

Griliches also finds that:

- spillover effects are significant in practice;
- social rates of return exceed private ones;
- basic research is particularly cost effective;
- there is a relatively low return to government support of private R&D.

Griliches concludes: "Given good data, [this approach] can tell us something about average returns to R&D investments in the past and whether they appear to be changing over time. It may be able to indicate industries where returns have been especially high or low, but it will not be able to tell us whether a particular proposed R&D project is a good bet or not". Recent work by Capron and van Pottelsberghe[24] also suggests a generally high rate of return to R&D, but results vary greatly between countries and are subject to considerable uncertainty.

Among other econometric work, Calvert *et al.*[25] have examined the relationship between export shares and innovation output at the firm level, using data from the CIS mentioned earlier. This shows a positive and significant relationship between innovation outputs and export shares, at the company and industry levels. Earlier studies also examine the significance of innovation for export performance in OECD countries at industry and national levels. Soete[26] considers the relationship between numbers of patents issued in the US by various foreign countries, and their shares of world exports. Fagerberg[27] looks at the effect of R&D and world patenting on productivity, using cross-sectional data (yearly averages) for a number of countries for the 1973–83 period. Both authors find an important role for innovation in export performance. Fagerberg finds that both R&D and patenting yield very statistically significant results, with the correlation between productivity and patenting being closer than that between productivity and R&D.

At the micro level, the extensive literature review by Dosi[28] on the effects of innovation on the firm stresses the complexity and dynamic nature of the innovative process within firms and industries, and the heterogeneous structures that result. "Nothing similar to the 'representative firm' stylised by economic theory seems to emerge from empirical accounts". There is no clear general message here on the virtues or follies of innovation by firms—innovation and adoption of technologies are part of overall firm strategy, and for success must be carried out in a way appropriate to the attributes of the particular firm at a particular time and in a particular environment.

At one level, of course, casual observation shows that it is obvious that innovation is vital for growth and the maintenance of competitiveness. In the modern developed world, no farmer with non-hybridized seed varieties and a scythe can hope to compete with one using modern hybrids and a combine harvester. But it is the successes that we hear about. The what, why, how and when of innovation are crucial to success and failure.

Clark[29] argues that the foundation of a firm's competitive position lies in its attributes and the capabilities it can bring to the market-place, and that "the significance of a change in technology for competitive advantage depends on 'transilience'—that is, its ability to influence the firm's existing resources, skills and knowledge". She cites several examples, including the introduction of the Bessemer process in steelmaking in the 1850s. Difficulties and dangers associated with implementation highlighted the need for access to architectural, managerial and technical expertise, which 'weeded out' many firms.

Broadly similar conclusions are reached in a recent Dutch study of relationships between innovative effort and business performance.[30] A paired-comparison technique is used, each pair of firms comprising a 'leader' and a 'follower'. The leader in each pair is identified as the more innovative firm, but in other respects (size, market, etc.) the members of each pair are similar.

The 'leader' firms are generally found to be better performers in terms of profit, rate of return and turnover per employee. But the underlying differences are not related simply to the more rapid adoption of new technologies. The leader companies showed a stronger external orientation, a greater emphasis on human resource development, and stronger links with clients, technical management and marketing competence.

A similar package of interrelated attributes is found to be generally associated with innovative success in a study by INNO in Germany.[31] The stress here is on the importance of 'interweavement'—relationships between the firm and outside bodies, in particular clients, suppliers, universities/research institutes and consultants. In general, firms with stronger links with such bodies are most successful, and typically it is larger firms which have stronger links.

Economic Models

With the notable exception of the work of Schumpeter,[32] the great majority of the structured economic thinking on technical change up to the 1970s was in the 'neoclassical' tradition, exemplified by the early econometric work of Solow mentioned earlier.

Solow's finding that a large part of the growth in national output is not explained by increases in volumes of inputs has commonly been interpreted as reflecting the productivity-enhancing effects of technical change, and demonstrating its importance for economic growth. However, many regarded the 'exogenous' treatment of technical change, where the improved performance is not explicitly related to expenditures or volitional activities of any kind, as unsatisfactory, and it tells us little of direct relevance to policy. As an attempt to represent technical change as an integral part of the growth process, the notion that improvements in technology are frequently incorporated or 'embodied' in new plant and machinery was incorporated in the so-called 'vintage' class of growth models.[33]

In each time period, investment expenditures are made in 'best-practice' technologies which remain in use until they become technologically obsolescent, normally at the point where (under rising real wages) they cease to yield a positive return. Overall productivity is dependent on the technological characteristics of the spectrum of vintages in use at any time, and increases according to the rate of change of 'best practice' and the volume of expenditure in it. These models are useful in emphasizing the importance of improvements in the capital stock and the centrality of the diffusion process for the economic impact of innovations, but tell only part of the story in their neglect of the importance of what are now called 'intangible investments'. They are also notoriously 'data hungry' and difficult to estimate. Recent developments are described in Silverberg and Verspagen.[34]

A further development occurred with the increase in 'evolutionary' thinking regarding technical change and economic progress. Frequently, the evolutionary model was, and is, contrasted—generally favourably—with its 'neoclassical' counterpart. The first evolutionary modelling work to obtain prominence was that of Nelson and Winter.[35] The basic units of analysis are a large number of hypothetical firms using particular technologies defined by labour/output and capital/output ratios. As wages rise, the rate of return of a firm using any fixed technology declines; when it falls below a particular arbitrary value, the firm will 'search' for an improved technology, its chances of success being dependent on the 'distance' between the new technology and its current one. Some firms 'die', others are 'born', and over time the model generates an aggregate path (obtained from the totality of 'live' firms) which appears to be consistent with the actual economic development of the US in the first half of the twentieth century. The authors argue that the model is quite as effective as the neoclassical orthodoxy in explaining aggregate trends, but from a more realistic micro-economic basis.

This work has inspired a number of 'second-generation' evolutionary models, described by Silverberg and Verspagen.[36] These models differ mainly in respect of available technologies and search mechanisms. In all cases, these two factors provide the engine of economic growth, but detailed results vary considerably depending on the specification chosen.

Current Research

As part of this study, we circulated a questionnaire to some 500 active researchers and research sponsors in the fields of innovation and/or competitiveness, the great majority of whom are working in Europe. Information was sought in five main areas:

- main activities (teaching, research, consultancy, etc.);
- key researchers;
- critical documents;
- main issues covered;
- key findings.

Figure 3 summarizes the coverage of the research carried out by the 50 or so respondents in terms of the issues tackled by their work and 'levels' of coverage. The issues addressed were classified as:

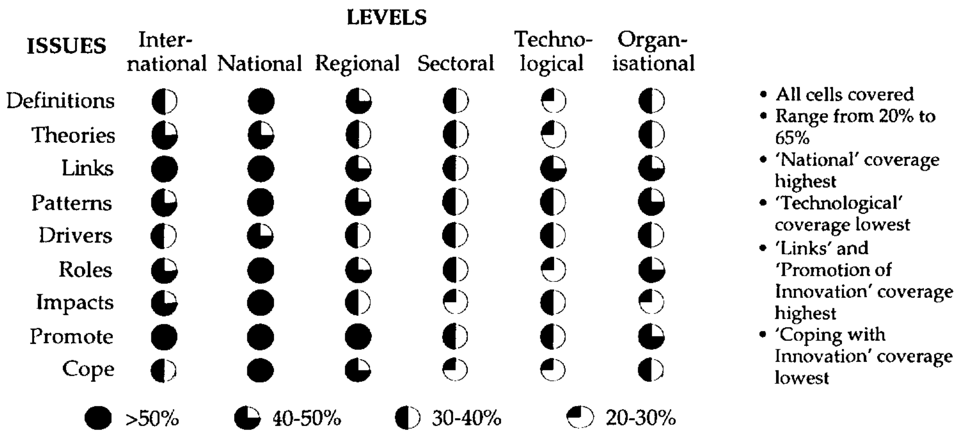

Figure 3. Coverage of innovation and competitiveness issues.

- *Definitions*: definitions and indicators of innovation and/or competitiveness.
- *Theories*: theories and models of innovation and/or competitiveness.
- *Links*: the links between science, technology, innovation and competitiveness.
- *Patterns*: structure, organization and patterns of innovation.
- *Drivers*: the drivers and motors of innovation.
- *Roles*: the roles of the main actors involved in 'systems of innovation'.
- *Impacts*: the impacts of innovation.
- *Promotion*: policies and strategies to promote innovation.
- *Coping*: policies and strategies to cope with innovation.

As can be seen, the national level of analysis is the most comprehensively covered, while 'the links between science, technology, innovation and competitiveness' and 'policies to promote innovation and competitiveness' are the most frequently encountered issues. Relatively few researchers are specializing in particular technologies, or are working on methods of coping with technological innovation.

Figure 4 shows how the current research of our respondents matches the EU Directorate-General III's (DGXIII's) four main objectives and six areas of activity. This shows that most current work should be of interest to those parts of DGXIII concerned with broad issues of industrial policy, while the objective of strengthening competitiveness is also central to most of the research conducted. In contrast, the objective of promoting intangible investment receives a relatively low level of coverage, despite its perceived importance. The broad interest in information technologies reflects their pervasive nature and the critical role they play in modern industrial economies.

A marked feature of current research is an increasing tendency towards a 'systems' or 'holistic' approach, reflecting an appreciation of the interrelatedness and complexity of the innovation system and the limitations of treating parts of it in isolation. In addition, there is a perception that what might be called the turbulence of the system is currently high: that we are in a period of radical and uneven technical change, with volatile demand for a changing range of products (see Figure 5). The relationship between innovation and competitiveness is simpler to understand in relatively stable (i.e. slowly evolving) supply and demand conditions, and becomes much harder to deal with in times of turbulence. Consequences of turbulent supply and demand include:

- a constant need for flexibility and adjustment in the production or transformation

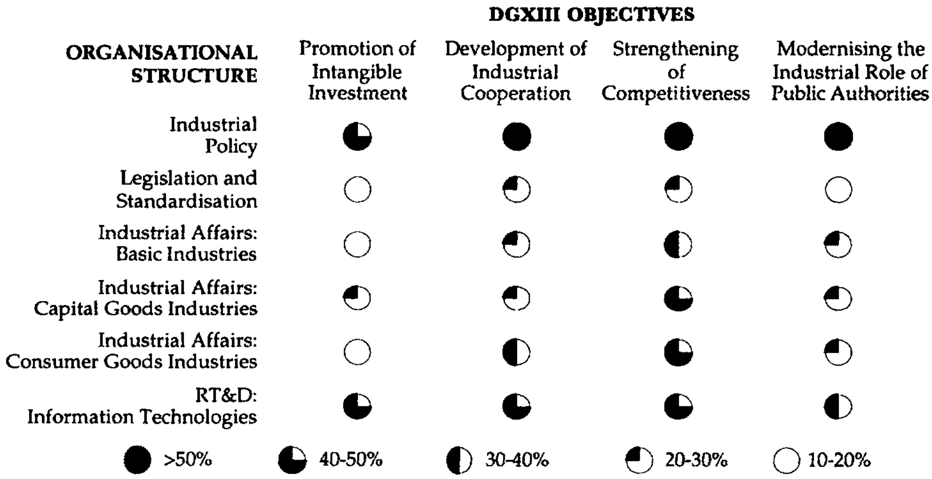

Figure 4. Match with DGXIII objectives and structure.

process, with continuous technological, organizational and inter-organizational realignments needed to cope with change;

- the transience of any one solution to the problems created by turbulence.

Innovation and Competitiveness in the EU

As mentioned, the 'World Competitiveness Report', published jointly by the World Economic Forum (WEF) and Institute for Management Development (IMD) in Switzerland, contains 'league tables' illustrating the relative competitive positions of major industrialized countries. The two bodies now use somewhat different sets of indicators,

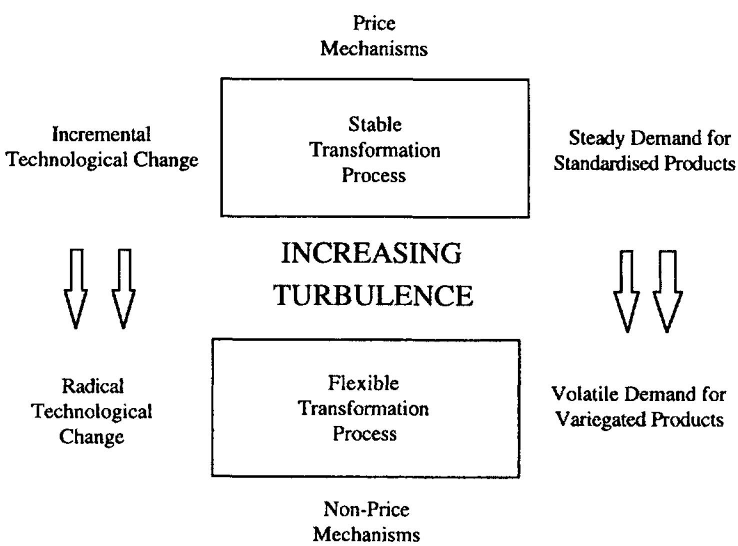

Figure 5. Increasing turbulence.

Table 2. WEF and IMD competitiveness rankings, 1996

Country	WEF	IMD
Singapore	1	2
Hong Kong	2	3
New Zealand	3	11
US	4	1
Luxembourg	5	8
Switzerland	6	9
Norway	7	6
Canada	8	12
Taiwan	9	18
Malaysia	10	23
Denmark	11	5
Australia	12	21
Japan	13	4
Great Britain	15	19
Netherlands	17	7
Germany	22	10
France	23	20
Belgium	25	17
Italy	41	28

Source: Economist, 1 June 1996.

resulting in some significant differences in rankings. But the EU countries generally do not do well under either system. Table 2 provides a selection from the 1996 rankings. The main reasons for the poor showing of EU countries appear to be their relatively high tax rates and inflexible labour markets (*The Economist,* 1 June 1996).

Europe is also argued to be in a poor competitive position in the EC White Paper *Growth, Competitiveness and Employment.*[37] The Commission finds that, over the past 20 years:

- the European economy's potential rate of growth (i.e. the estimated growth rate which is sustainable for many years without causing problems of 'overheating') has shrunk from around 4% to around 2.5% a year;
- unemployment has been steadily rising from cycle to cycle;
- the investment ratio has fallen by five percentage points
- the EU's competitive position in relation to the US and Japan has worsened with regard to employment, shares of export markets, R&D and innovation, and its incorporation into goods brought to the market, and the development of new products.

Some of these trends are shown graphically in Figures 6 to 9. The Commission regards the break in trend in corporate R&D expenditure in 1992 as 'very worrying'; as well as the decline in growth rate, expenditure on R&D as a proportion of GDP is lower in the EU than in the US or Japan.

Policies proposed in the White Paper for ameliorating the situation are shown in Table 3. Incentives for increases in R&D and technological diffusion are advocated, as are policies to promote 'intangible' (non-physical) investments, and measures to improve relationships between large firms and subcontractors, between producers and users, and collaboration networks.

Andreasen *et al.*[38] draw similar conclusions about the reality of the decline in the EU's

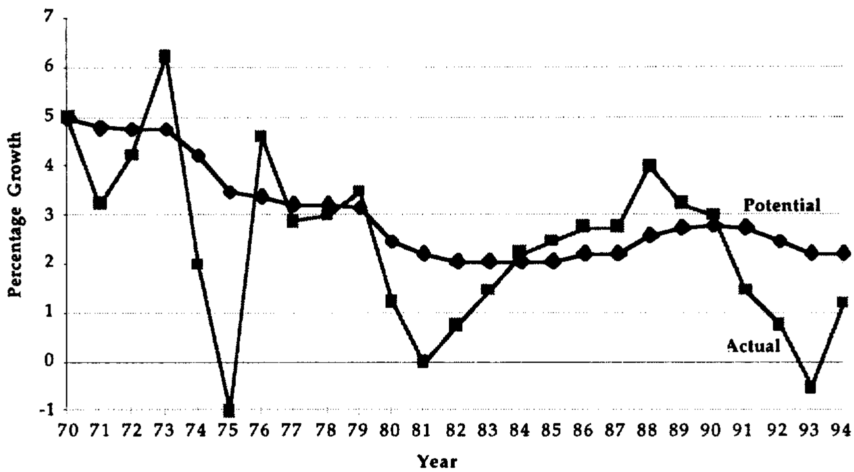

Figure 6. Actual and potential rate of GDP growth in the community.[37]

competitiveness, but have rather different policy prescriptions. They note that the EU has a substantially higher expenditure than the US or Japan on academic (presumably scientific) research, but has a lower industrial R&D spend as a proportion of GDP, and a lower percentage of patents in the US market, than those two countries. These figures are interpreted as indicating a broadly satisfactory position in research, but a weakness in translating research into innovation—the 'research paradox'—though this is a somewhat shaky conclusion perhaps, with the R&D figures being rather glossed over, and much being made of the unsurprising conclusion that US firms have a high propensity to patent in the US. Nevertheless, with additional evidence from a number of case studies on the failure to reap productivity gains via the effective diffusion and utilization of technology, they further conclude:

> The decline in European competitiveness cannot be ascribed to the failure to invest in technology, in terms of R&D expenditure, investment in new production

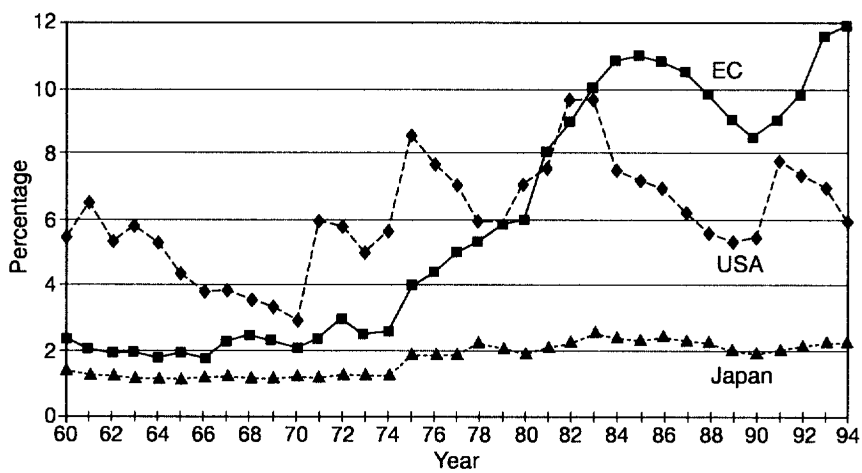

Figure 7. Unemployment in the EU (percentage of the civilian labour force).[37]

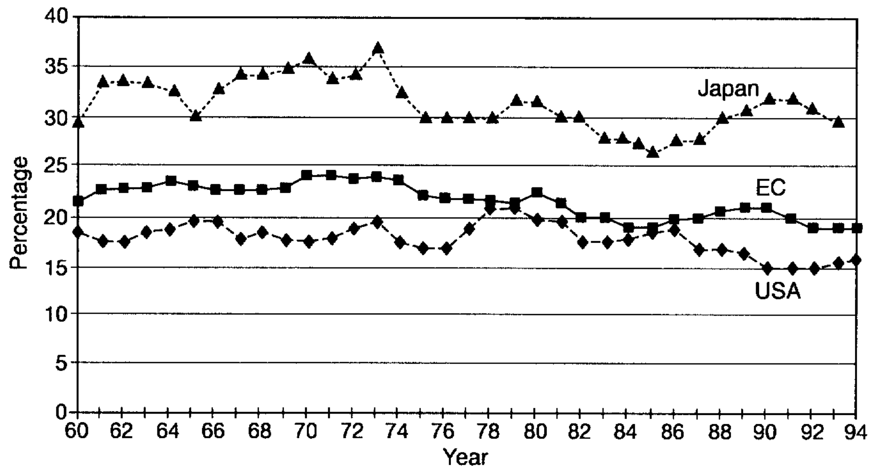

Figure 8. Investment shares: EC, US, Japan (percentage of GDP).[37]

technologies or in assisting 'national champions' in their technological endeavours. Instead, we can witness what we have termed the productivity paradox. Many of the classical instruments of 'technology' are in place, often in quantities which are superior to those of many of our major global competitors. Yet our relative performance has declined over the past decade and looks likely to continue unless there is a major change in direction.

The existence of this productivity paradox is explained by what we have termed the 'missing link'. By this we refer to the inability of European producers to translate their impressive technological investments into marketable goods and services with adequate alacrity, differentiation and quality, and at competitive prices. The source of this missing link is to be found in a cluster of organizational innovations.[39]

Although not all would agree that this is the only issue on which attention should be

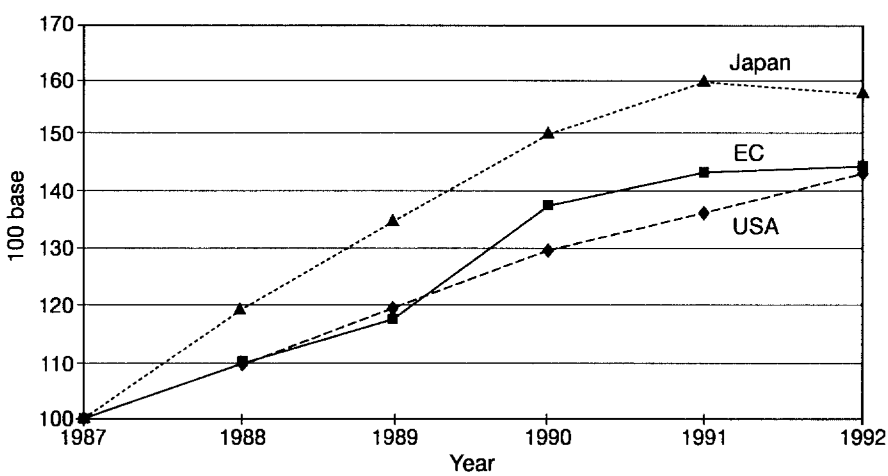

Figure 9. Growth of R&D expenditures.[37]

Table 3. EC Guidelines for a policy of global competitiveness[37]

Objectives	**Means**
(1) Helping European firms to adapt to the new globalization and interdependent competitive situation	• Capitalizing on the European Community's industrial strengths • Developing an active policy of industrial cooperation • Establishing a concerted approach to strategic alliances • Targeting measures to ensure the competitive functioning of markets
(2) Exploiting the competitive advantages associated with the gradual shift to a knowledge-based economy	• Reforming tax policies so as not to create employment disincentives and to promote incentives for the efficient use of scarce resources • Developing a policy to encourage 'non-physical' investment (training, research, technical assistance) • Bolstering policies to streamline and rationalize rules and regulations • Reviewing the criteria governing the use of public instruments in support of industry so as to enhance their impact on the growth of value added and employment • Launching a European policy aimed at quality
(3) Promoting a sustainable development of industry	• Increase substantially and coordinate R&D efforts in the field of clean technology • Develop economic incentives to support the diffusion of R&D results into products and processes
(4) Reducing the time lag between the pace of change in supply and the corresponding adjustments in demand	*Demand-side measures* • Pursuing initiatives aimed at facilitating a concerted revival in consumption at world level • Promoting the emergence of new markets *Supply-side measures* • Encouraging continuing structural adjustment by supporting privatization • Underpinning the dynamism of SMEs *Measures to improve the relationship between supply and demand* • Facilitating partnerships between large firms and their subcontractors • Improving the interfaces between producers and users • Establishing collaboration networks so as to develop cluster of competitive activities

focused, there is an emerging consensus that, in the words of Rosenberg, "improvements in technology are far from being a sufficient condition for productivity growth".[40] He cites the example of huge investments by General Motors in robotics and other automated equipment failing to halt its declining market share in the US. It is also noteworthy that what is normally understood as the 'productivity paradox'—low productivity growth over the past two or three decades, despite no obvious decline in the rate of technological change—is at least as widely discussed in the US as in Europe, with no totally convincing explanations, although the increasing contribution to GDP of low-productivity service sectors probably plays a large part. And organizational innovations may well be of particular benefit for those sectors.

Policies Concerning Innovation and Competitiveness

Over the past 30 years or so, policies for industrial and economic development have increasingly encompassed measures designed to support and encourage technological change. The form these measures have taken has in turn evolved as our understanding of the links between innovation and competitiveness has increased. In this section, we review the influence that the neo-classical and evolutionary traditions of thinking outlined in the previous section have had on the role and relevance assigned to public policy for fostering innovation and competition. In particular we note how 'evolutionary' thinking and our appreciation of the complexity of innovation processes have given rise to a rich mix of policy instruments and their eclectic use in different settings.

Neoclassical Perspectives

The neoclassical tradition typically sees the role of public policy as one of correcting market failures; for such thinkers, policy should involve moving the system towards the ideal general equilibrium position, although there is variation in views on how far from that ideal we would be without government intervention. An extreme view, which has attracted some support, is that of Kealey.[41] He asserts that market failures do not exist at all, and hence that there is no role whatsoever for public support for R&D and innovation. Kealey believes that not only should all subsidies to industry and other forms of aid cease forthwith, but that all public funding of civil R&D, both in government research laboratories and in academia, is counterproductive.

Discussions of market failure centre on the idea of 'spillovers' or 'externalities' introduced in the previous section, whereby the benefits of R&D and innovation do not all fall to those who bear the costs. Arrow[42] demonstrated theoretically that spillovers of technical knowledge generated by R&D and innovative activity, which could be appropriated by others, could be expected. As pointed out by Lipsey and Carlaw,[43] this would not be a problem for firms concerned about spillovers provided that a perfect patent system could be implemented, giving an absolute right of monopoly use of knowledge to the creator of that knowledge. But, "in reality, property rights to knowledge are highly incomplete, leading to the prediction that knowledge-creating activities such as R&D will be below the optimum rate'.[44] Hence the need for public policy to encourage such activities.

The evolutionary (or 'structuralist') alternative to this neoclassical argument would not deny the existence of externalities. Where the structuralist alternative differs is in questioning the desirability or need to 'correct' for spillovers—the innovator may realize sufficient benefits not to be discouraged even if there is some sharing of the rewards of his/her work. Structuralists would also stress a far wider range of issues as relevant to the policy debate—in particular the historical and structural context, and the role of institutions, neither of which appear in standard neoclassical analysis.

National Systems of Innovation

The concept of 'national systems of innovation' is now widely used within the structuralist/evolutionary camp. Metcalfe describes it as follows: "That set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies, and which provides the framework within which governments form and implement policies to influence the innovation process".[45] The concept seems to have been inspired partly by interest in the technological rise of Japan, with its idiosyncratic institutional environment.[46] The performances of the Asian 'tiger' economies in the early 1990s provide other examples of nation-specific behaviour. The idea of national systems

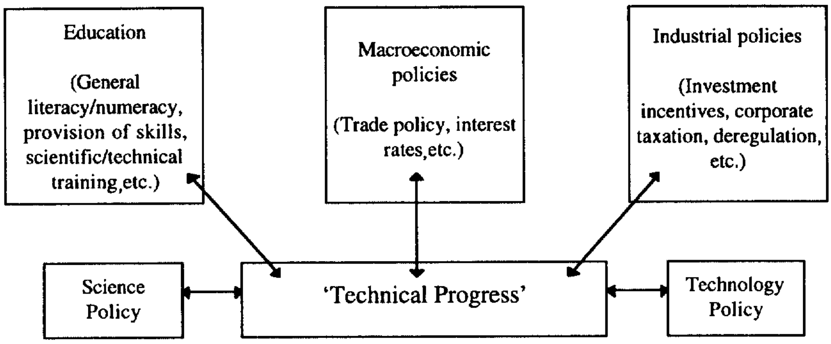

Figure 10. Policy and technical progress.

of innovation is clearly consistent with the view that similar science and technology policies should not necessarily be followed in all countries.

The policy implication of considering innovation from a 'national systems' viewpoint is that attention becomes directed principally towards the interactions between the actors involved, including bottlenecks such as mismatches between supply and demand for technology, and deficiencies in information flows.[47]

Science Policy, Technology Policy and Innovation Policy

'Science policy' is normally distinguished from 'technology policy', the former being designed to increase basic knowledge. While the interactive model of innovation suggests some blurring of the distinction, the institutions involved in the two activities are often, if only for historical reasons, separate. Dodgson and Bessant[48] add a third category, 'innovation policy', which includes policies designed to facilitate innovation and diffusion, principally by stimulating flows of technology and information between firms and other institutions. Here, just as we interpret the word 'innovation' as used in the title of this review to cover all phases of the process of the development, application, adoption and diffusion of technologies, we shall use the term 'innovation policy' similarly broadly, and synonymously with 'technology policy' (where the word 'innovation' is used in the more restricted sense of the first commercial application of a new product or process, this is made clear in the text).

Although most of the discussion in this section will centre on 'innovation policy' thus defined, a wide range of other policies not explicitly intended to affect innovative behaviour are likely to have a significant influence on it. For example, the importance of general high levels of education in aiding speedy diffusion of technologies has been stressed by several authors.[49] General industrial policy, such as investment incentives, also clearly has a major role in assisting dissemination of improved techniques, and may produce more immediate results in this regard than stimulants to innovation. Moreover, positive correlations between economic performance and innovation, noted earlier, almost certainly reflect causality operating in both directions,[50] so that the ability or otherwise of policy-makers to stimulate the economy will itself have implications for technical development. Figure 10 illustrates some of the policy influences on technical progress.

We now move on to discuss a range of policy instruments, drawing heavily on the work of Guy and Arnold[51] and the excellent survey by Mowery.[52] Defining technology policy as "policies that are intended to influence the decisions of firms to develop, commercialise or adopt new technologies", Mowery points out its increasing importance in recent years. "Intensified international competition in technology-intensive industries, and the apparent success of Japan (as well as other economies in the Pacific Basin) in implementing 'strategic' technology policy also has increased the interest of scholars, policy makers and managers in the use of technology policy to enhance innovative and economic performance".

Broadly, then, governmental innovation policy can be viewed as prompted to some extent by a need to rectify the failures of the market identified earlier—in particular, the unwillingness of risk-averse suppliers to invest in R&D up to the socially optimal limit when they may be unable to appropriate all the rewards, leading to sub-optimal levels of invention and innovation (i.e. first commercial use). Also important, particularly from the evolutionary/interactive perspective, can be the lack of awareness or inability of users to adopt new technologies and take advantage of their benefits—sometimes referred to as 'systemic' failures. These can lead to inadequate rates of diffusion, i.e. rates or levels of adoption of technology by users other than the original innovator.

Various typologies of innovation policies are possible. Here, we choose to divide them into those designed to stimulate the supply of technologies, those concerned with stimulating or satisfying the demand for technologies, and those principally concerned with improving information flows by developing networks or national infrastructure. This is similar to the classification used by Hanna *et al.*[53] and to that used by OECD[54] specifically for diffusion programmes:

Supply

- Basic research.
- Policies to support the generation of new technologies in industry: by complementing private R&D; by encouraging inter-firm collaboration; by targeting specific technologies; by tax breaks and subsidies for R&D; by strengthening intellectual property rights.

Demand/adoption

- Financial subsidies for adoption;
- Information provision.
- Technology transfer from abroad.
- Technical standards.
- Government procurement.
- Encouragement to small and medium-sized enterprises.

Networking and developing research infrastructure

- Improving industry–university relationships.
- Developing other infrastructure elements.

Policies for the Supply of Technology

On the supply side, the recognition of the non-linearity of the innovation process has called into question the traditional preoccupation of public bodies with the pursuit of basic research, unrelated to recognized market needs—although such research still accounts for most publicly-funded R&D in industrialized countries.

Basic research. This covers work carried out in universities, technology centres and government laboratories, normally at public expense. The recent PACE study,[55] conducted by the Maastricht Economic Research Institute on Innovation and Technology, and funded by the EU, involves a survey of large European industrial companies on innovation-related issues, including the role of public research. The links between basic research and industry are found to vary greatly between countries and between industrial sectors—utilities, pharmaceuticals, aerospace and food are the sectors with the strongest links. Overall, around one-third of the firms surveyed consider the output of public research institutes to be 'important' to them.

A recent Science Policy Research Unit (SPRU) report on the relationship between basic research and economic performance concludes, somewhat tentatively, that "publicly funded basic research seems to have had a substantial impact on productivity, and that trend is likely to continue".[56] Like some other commentators, the report points out that many evaluations of publicly funded basic research take account only of the more observable direct effects, thereby undervaluing its benefits. Basic research is now widely seen to have important, but indirect, effects on industrial innovation—for example, in providing information, in contributing to the training of scientists and engineers and in the development of new research techniques. The SPRU report also identifies a change in the expectations state and society have of basic research: "We are witnessing the emergence of a new 'social contract' for basic research, under which the public and government expect more direct and specific benefits from their investments in this research". Perhaps as a response to such pressures, in the US and Western Europe in particular, public funding is increasingly directed towards direct links with industry. While supportive of the general principle of publicly funded basic research, the SPRU report doubts whether the benefits are clearly demonstrable. "Technology foresight offers one means to link research to longer-term economic and social benefits. However, there are currently no methods for estimating the value for money from publicly funded basic research in a reliable manner".[57]

Complementing private R&D. Studies suggest that direct government support for industrial R&D has a smaller effect than private R&D expenditures,[58] although this may be because externalities or 'spillovers', likely to be higher with such funding, are underestimated in the evaluations. Generalizations on 'additionality'—the issue of whether government R&D support substitutes for private funding, complements it or stimulates it—are difficult to make from the literature. Different conclusions are reached by contributors to Griliches and to Link.[59] Recent econometric work by Capron and van Pottelsberghe[60] has reached similarly ambivalent conclusions, with public R&D subsidies found sometimes to stimulate and sometimes to inhibit private R&D, depending on the particular country or industrial sector. Quintas and Guy[61] provide evidence that much R&D carried out within the context of publicly supported collaborative R&D programmes complements in-house R&D by facilitating the conduct of 'insurance' R&D, i.e. work allowing firms to cover or explore alternative technological options normally out of their reach.

Encouraging inter-firm collaboration. Inter-firm collaboration in R&D has potential advantages—not comprehensively researched—of reducing costs, reducing duplication of effort, spreading risk and providing economies of scale.[62] Evidence from Japanese experience suggests that cooperative ventures tend to be more successful if private funds, as well as public, are involved, and if industry, rather than government, sets the research agenda.

Mowery[63] has reviewed the considerable growth in collaborative ventures between US and foreign manufacturing firms. He concludes that the results have in many cases been positive for the firms involved and for the economy as a whole. He sees little place for comprehensive public policy in this area—in particular, restrictions on collaborative ventures are likely to be detrimental to competitiveness, rather than conducive to it. Public science and technology policy should focus on rapid domestic diffusion (adoption) of technologies, rather than solely the generation of new knowledge.

A National Academy of Engineering (NAE) study of foreign participation in US R&D[64] highlighted two facets of globalization:

- a deeper integration of the world's major national innovation systems through the activities of multinational corporations (MNCs) and individual scientists and engineers;
- a corresponding convergence of the industrial and technological capabilities of industrialized countries.

A corollary of these trends is the increasing need of MNCs and other leading edge technology firms to drink from and replenish the global pool of technological know-how. There is thus growing support in the industrial community for a more open global system for the conduct of scientific and technological research, the exchange of know-how and access to complementary assets. In response, the US has increasingly passed legislation insisting on reciprocity as a condition for the participation of foreign firms in publicly funded technological activities.

The NAE study also notes, however, that foreign participation in R&D funded by the US government is regulated by a patchwork of confusing—and sometimes contradictory—agency directives, all of which act to restrict collaboration. The study recommended that Congress strike reciprocity requirements from existing laws governing federal R&D spending and exclude them from future R&D legislation, noting that the potential benefits of reciprocity requirements were small and offset by the costs involved. They were difficult to police and administer, and encouraged other nations to follow suit. Guy *et al.*[65] point out that the NAE argument is directed against the way in which reciprocity is handled in the US, not against the advocacy of reciprocity itself. Handled the wrong way, insistence on reciprocity in individual cases can be an effective block on the participation of foreign firms and an obstacle on the path towards a more open global system of technological intercourse. The implementation of reciprocity should involve the negotiation of more comprehensive bilateral and multilateral agreements, not the case-by-case application of stifling legislation.

Major Western cooperative ventures initiated early in the 1980s included Sematech in the US (a semiconductor manufacturing consortium) and ESPRIT in the EU, both involving government funding for 'pre-competitive' research on IT. Numerous other programmes followed at national and international levels. Verdicts on the success of such programmes are mixed.[66] Evaluations generally consider issues such as the appropriateness of initiatives, the efficiency of their implementation, and effectiveness in terms of goal attainment and impact.[67] In these terms, many initiatives can be characterized as 'the right thing done moderately well but with limited impacts'. Although technical targets are often reached, and 'networking' goals to help establish a shared technological base and consolidate overall technological capability in the network of participating organizations, exploitation-oriented goals are often only slowly realized. To a large extent, however, this is a function of overly grandiose aims and a lack of appreciation of the non-linear ways in which technological capability is translated into commercial success.

Fostering particular technologies. This approach has a long post-war history, and is most recently associated mainly with electronics, information and communications technologies. Problems have included a tendency for competitiveness to be reduced by the creation of near-monopolies, and difficulties over judgements of feasibility and market demand. Mowery[68] identifies a separate strand of policy—'generic' technology development—involving the targeting of an intermediate stage in the innovation process. Examples include the ESPRIT, RACE and ACTS programmes in the EU.

Tax incentives and subsidies. Tax incentives for R&D are widely used in developed economies, although there is substantial variation in their extent. According to Mowery,[69] citing research by Mansfield,[70] these have been less effective than direct grants in stimulating research activity, and (at least in the US) have led several firms to classify other expenditures as R&D. Reviewing the impact of R&D tax credits in the US, Cordes[71] concludes that there has been some influence on firm behaviour, but it is not certain whether this has been to increase total R&D, or has merely diverted spending from areas that do not qualify for the credit to those that do. Overall, the value of tax incentives remains unclear. Tax incentives offer a method of providing a direct counter to the 'market failures' associated with the 'spillover' effects resulting from the lack of full appropriation of benefits by the innovating organization, and have the advantage that they involve less interference in the market than selective subsidies, and do not require difficult judgements.

According to a review by OECD,[72] 'best practice' R&D tax policies should:

- be designed as part of an overall strategy to stimulate innovation in industry, and should complement other science and technology policies;
- include provisions for the deduction of all qualifying R&D expenses in the year in which they are incurred;
- be flexible; for example in allowing deductions to be carried forward where a firm has no tax liabilities in a given year;
- be assessed on a country-by-country basis, since benefits depend on overall tax systems;
- consider including special provisions relating to small and/or new firms, in order to encourage entrepreneurship and innovative start-ups.

The suggestion of considering tax incentives in the context of the overall system of innovation is in line with the 'interactive' model of the innovation process, and a similar suggestion could be made regarding any technology policy measure. The next three proposals in the list above are designed to strengthen the appeal of the system, while the last proposal in the list reflects widespread current thinking on the need to encourage small and medium-sized enterprises in particular.

Intellectual property rights. The argument for awarding intellectual property rights (IPRs), such as patents and copyrights, is to provide an incentive to innovate which would be lacking if others could instantly appropriate an innovator's ideas. IPRs thus encourage innovation. But they can also inhibit diffusion, so that the objective of stimulating the use of new technologies in an economy or region via IPRs involves a balancing act. They should give sufficient protection to encourage innovation, but not go beyond this. Lipsey and Carlaw[73] give an example which suggests that actual patent policy may be way off-beam in this respect, citing a report on Canadian pharmaceuticals arguing that a five-year time period for patent protection would be more appropriate than the 20 years actually in operation.

Infrastructure links and networks. There are many examples of governmental attempts to encourage innovation-related networks, which, as discussed earlier, are seen as centrally important for successful innovation. Examples include the regional systems of innovation centres in the Netherlands, which act as intermediaries between firms and research centres, and the multi-faceted German network-based strategy.[74]

University–industry cooperation provides one example of where governments have sought to foster links between actors in the innovation infrastructure. Early European initiatives in this area included national programmes such as the UK government's Alvey programme, and many of the cooperative 'pre-competitive' research programmes running under the umbrella of the EU's Research and Technological Development Framework Programme involve university–industry collaboration. Envisaged benefits from university–industry cooperation include a stimulus to innovation by the exposure of university research to industry, the encouragement of more industrially oriented research by universities, and the encouragement of more industrially relevant training of young scientists and engineers. Feller[75] provides a counter argument. In particular, he argues that to encourage or force academic researchers to participate in commercial ventures generally does little for university revenues, and diverts researchers from the social roles at which they are most efficient. The evidence suggests that the benefits of university–industry cooperation are potentially high, but not normally in the direct form of new innovations or other intellectual property.[76] This emphasizes the importance of 'tacit' information for successful innovation.

Science parks, set up by public administrators at national or local level, comprise various firms and other institutions in close proximity, often explicitly for the encouragement of innovation-related networks. From a regional development perspective, science parks are a potential growth pole for the local economy. Guy[77] observes that the main growth routes involve agglomeration, synergy and firm expansion, i.e.

- an increase in the number of firms in the local economy;
- the extent to which they interact with each other and with other major actors;
- the expansion and growth of individual members of the clusters formed.

The attractions and benefits of agglomeration and synergy are often unrelated to technological interaction, either between firms and academic sources of knowledge or between firms themselves. Firms cluster together to be near to customers and suppliers and to reap the benefits of 'image', an attractive business environment and other infrastructural features (telecommunications, transport and access to sources of skilled labour). Science parks often provide a conducive environment in which high-technology firms can benefit from non-technical interaction. In many science parks, however, an underlying premise is that parks provide a mechanism allowing (public sector) knowledge bases (e.g. higher education institutes, government research establishments and other research and technology organizations) to be exploited by firms via:

- recruitment (e.g. firms treating universities as an employment pool);
- spin-offs from the universities and research institutes;
- technological interaction (one-off transfers, licensing agreements, R&D collaboration, continuous interaction, synergistic relationships, etc.).

As pointed out by the OECD,[78] tax incentives to hire researchers are a means of bringing individuals who may belong to extensive networks into firms. That report also points to laboratories and private industry. However, as Mowery[79] points out, public laboratories frequently have expertise in areas (often defence) not directly related to industry needs:

> The limited success thus far of US Government efforts to spark technology transfer from public laboratories to private firms is attributable in part to the flawed premises of many of these recent initiatives. Rather than 'supermarkets of technology', the historic mission of many publicly-funded laboratories in the US and other industrial economies means that much of their in-house 'technology' (as opposed to capabilities) may be of limited interest to industry. Programmes promoting technology transfer also often underestimate the complexities and difficulty of this task, especially when it involves firms not previously involved with these laboratories.

Policies to Promote Technology Adoption

As Arnold *et al.*[80] point out, it is surprising that invention and innovation tend to receive more public support than technology adoption and diffusion, despite the greater economic impact of the latter. However, this situation may be changing. Policies to improve firms' technological capabilities are, probably rightly, receiving increasing attention.

Subsidies for adoption. These include tax incentives for the acquisition of specified kinds of equipment. Although they are quite widespread, there is apparently almost a complete lack of evaluations of such schemes, except for the case of Japan.

Information provision. A number of awareness campaigns, mainly around information and communication technologies (ICTs), are currently running around the world (the Information Society Initiative in the UK, for example, contains a number of 'awareness' elements). The EU is currently carrying out an extensive EU-wide survey of information society projects, initiatives and participants (European Survey of Information Society), which has information provision as a major objective. The hope is that the inventory produced will be used as a tool for knowledge, communication, partnership and the promotion of best practice across Europe.

Technology demonstration projects provide another example, where public funding is used to sponsor preparation of a facility showing the capabilities of a technology, and its subsequent demonstration to potential users. In the UK, the Multimedia Demonstrator programme aims to demonstrate not only technologies but also the business opportunities presented by new digital media technologies.[81] Baer *et al.*[82] reviewed 24 demonstration projects in the US, and identified features leading to rapid adoption: low technological uncertainty, cost-sharing opportunities, strong private sector networks and realistic time constraints. They comment "that demonstrations with these attributes achieve greater diffusion success than others is hardly surprising: what is surprising is that so many past demonstrations have not incorporated them into planning and operation". Policies involving the provision of advisory services, especially to small firms, are reviewed by Arnold *et al.*,[83] including such measures as a registration system for the 'quality control' of consultants, and the provision of 'mentors' with company backgrounds to assist the development of small companies.

Strategy development. Recent 'catalytic' EU initiatives have provided support for individual regions within the EU to formulate and develop innovation-related strategies which span technology generation and diffusion. These schemes include the Regional Technology Plans (RTP), Regional Innovation Strategies (RIS) and Regional Innovation and Technology Transfer Strategies (RITTS) of DGXVI and DGXIII. In the field of ICTs, the Inter-regional Information Society Initiative (IRISI) was a pilot action involving six regions—later expanded to 29—which allowed regions to explore how they might best enter the 'information society'.[84]

Government procurement. This can promote advanced technologies directly, by providing a market, and indirectly, by providing a platform for demonstration and assessment. Defence procurement is a clear example of the former, and computer equipment of the latter. Government procurement has frequently led to a weakening of competition, as in the case of commercial aircraft, although there are examples from Japan and the US where the involvement of a number of firms in supplying to the government has stimulated rather than stifled competition.

Standardization. This can reduce costs and uncertainties, and hence stimulate innovation and diffusion. The ESPRIT programme, for example, includes the objective of reducing barriers to regional markets by supporting joint research on regional technical standards. However, according to Mowery, "little research has examined the overall national payoffs to effective systems for the establishment of technical standards, nor have the designs of effective and ineffective systems been analysed".[85]

Technology transfer from foreign sources. This involves the imposition of restrictions to domestic markets for foreign firms. For example, in Japan, there is a requirement that foreign firms license technologies to domestic firms in return for being allowed access to markets. In the EU, anti-dumping legislation has had the effect of inducing high-technology foreign firms to locate in Europe. Again, there seems to have been little analysis of the costs and benefits of such policies.

Some more 'hands-on' policy measures have involved support for technology transfer projects. In particular, the European Commission launched the Specific Projects Action Line (SPAL) as part of the SPRINT (subsequently the Innovation) programme. SPAL identified, selected and supported projects which presented an opportunity to study how diffusion projects worked and how they could be managed, and which had the potential to fulfil the overall aims of the SPRINT programme by promoting the rapid diffusion of new technology throughout the EU. Many of the lessons learned can be found in Guy and Arnold and in Guy.[86]

Encouragement to small and medium-sized enterprises (SMEs). The belief that SMEs merit special attention is based on the argument that they are less well placed than larger firms to carry out internal R&D, or to obtain and adopt new technologies. Typically, they have fewer 'slack' resources to devote to 'intangible' investments (searches for information and improved technologies, training, networking, etc.). SME networks tend to be local and personal, with generally little interaction with government research institutes or universities. A particular policy suggestion to improve matters in this respect is the use of intermediaries to interpret or adapt the output of such bodies into a form usable by SMEs.[87]

In more detail, Arnold *et al.*,[88] in a discussion of policies to improve the 'technological capabilities' of SMEs, identify the disadvantages of SMEs compared with their larger counterparts as deriving from:

- the impracticability of internal R&D;
- their weak ability to interface with the external infrastructure;
- their focus on short-term problems, through financial necessity;
- their small, multi-functional and 'non-professional' management;
- the likely absence of key skills, such as engineering;
- difficulties in financing and implementing advice;
- risk aversion, necessitated by the serious consequences of failure;
- restrictions on the geographical extent of markets.

Arnold *et al.* advocate the provision of a range of services to enhance SMEs' capabilities, including 'proactive mentoring'—guidance on identifying and satisfying the needs of individual firms, in an analogous way to the agricultural extension services traditionally offered to farmers. The use of similar 'industrial extension services' has grown steadily over the past 20 years or so, but there is still scope for more efficient and effective implementation in many regional and national settings.

As pointed out by Arnold *et al.*, SMEs' links with the outside world are typically at the local or sector-specific level, through institutions such as chambers of commerce and trade associations. These links are exploited in some policy programmes. In France, for example, regional development initiatives such as science parks are strongly centred on chambers of commerce, while in the Netherlands, the SBI programme promoting IT to SMEs made use of the trade association network.

The diversity of assistance programmes for SMEs is noted by the OECD,[89] which put forward a three-fold classification of such schemes: dissemination of technology, transfer of information and training. Detailed analysis of programmes is considered to be "only too rarely undertaken".

Policy Trends in the EU

Over the past 30 years the range of policy instruments used to support science, technology, innovation and industrial development has broadened considerably, with the emphasis on different policy instruments shifting over time and from one country to another as perceptions of innovation-related 'problems' and their 'solutions' have evolved. Some of the shifts and trends can be summarized succinctly.

- There is increasing concern about the research and productivity paradoxes which have resulted in a development gap, i.e. the inability of many countries to exploit the science and technology base.
- Linear models of innovation are discredited, complexity and turbulence are recognized and appreciated, and 'innovation' and 'national systems of innovation' have become new buzzwords since developments inside innovation systems have been recognized as critical to the development of modern economies.
- There is an increasing focus on policies to promote the diffusion and effective utilization of technologies in order to close the development gap and resolve the research and productivity paradoxes.
- In some countries, particularly in less developed regions, only a small part of the science and technology base is relevant to the growth of a healthy secondary sector, and policies increasingly attempt to reorient this base.
- Many current policy initiatives are designed to unblock exploitation routes and bridge supply and demand.
- There is a marked growth in both the number and importance of intermediaries active in promoting and facilitating diffusion.

- There is an increasing emphasis on 'knowledge exploitation' policies designed to help SMEs, although larger firms continue to be the natural focus for 'knowledge creation' policies.
- Our understanding of what makes a balanced innovation policy portfolio is increasing, but it is still outweighed by our ignorance.
- Many innovation policies are inextricably linked with the aim of improving competitiveness, but sustainable development is an increasingly important factor in policy formulation.

Conclusions

The consensus of opinion, backed up by strong empirical evidence, is clearly that innovation has an important positive effect on competitiveness. The agreement starts to evaporate, however, when we ask whether there is enough of it; whether there should be more of it; and whether and how public policy can be used to stimulate it.

Estimates of rates of return to R&D certainly support the view that there is less R&D spending than is socially and economically desirable. This is perhaps particularly true in the EU, where only 2% of GDP is spent on R&D, nearly a percentage point less than in Japan and the US. The challenge is to know how to increase it, when the evidence on the effectiveness of almost all public policies is mixed or virtually non-existent.

In 1981, Rothwell and Zegfeld observed that "innovation policy is today more a matter of faith than of understanding". Even if this still has more than a ring of truth, things do seem to have moved on. The cynical view might be that all that has happened is that, with the failure of the earlier ideas to yield useful practical guidelines for policy, the models have simply been made more complicated, and a new set of buzzwords generated. In particular, the increased recognition of the importance of knowledge and organization has, unfortunately, not been accompanied by corresponding advances in our ability to measure these factors. Freeman[90] describes the little progress that has been made in this area, and considers it a big challenge to future research. But it is fair to say that new insights have been obtained, with lessons for policy. There is compelling evidence that certain contextual conditions are important for successful innovation, which, although recognized by some, were given insufficient emphasis earlier. It is also increasingly apparent that there are no simple solutions to extremely complex problems. We just have to live with the longer, more case-specific and interacting sets of factors, and perhaps set more limited and realistic goals for analytical policy analysis and for policy itself.

We can make a comparison with certain areas of natural science. There, the precision of analysis is sometimes convincing and impressive: for example, in the accuracy of forecasts of the arrivals and trajectories of comets. But elsewhere, theory can be woefully inadequate for practical purposes. An example is non-linear fluid flow—experimental wind tunnels are needed to test the aerodynamics of new designs of aircraft because the theory cannot cope. The system is just too complicated and difficult. Regarding innovation, what will succeed is unknowable in advance—we probably know more about the conditions under which an innovation process is unlikely to succeed. Further, evidence suggests that general-purpose policies are at best unreliable. The uncertainty surrounding the effectiveness of policy often seems as great as the uncertainty surrounding the innovation, with the added complication that we generally do not know whether policy has worked at the end of the day.

The situation might be described as the 'policy paradox'. With rapid technical change, and recognition of the particular importance and vulnerability of small firms, the need for public policy seems greater than ever. But precisely because of the rapidity, complexity and turbulence associated with present-day technical change and the wider economic environment, the efficacy and predictability of innovation policy is more than usually uncertain. Moreover, not only is the ability of policy-makers to exert a positive influence unclear, but actions that work today may be inappropriate in the changed environment of tomorrow.

Since innovation and competitiveness do appear to be connected, resolution of the research and productivity paradoxes described earlier is critical, but how can the policy paradox be overcome? And if innovation systems are so complex and the knowledge we have about their behaviour is so transient and ephemeral, how can analysis help the policy-maker?

In the first instance, policy analysis does provide a context for the application of policy, and some general indications of effectiveness. Beyond this, and in analogy with the wind tunnel, the best idea is perhaps to take account of the complexity through flexible, experimental approaches to policy, backed up by clear, well specified systems of monitoring, evaluation and benchmarking. Complicated systems can only be understood and mastered via systematized learning procedures. Understanding which types of innovation policy work in different settings requires an experimental approach and careful and considered evaluation of the results of these experiments.

Methods of evaluation themselves have been receiving increasing attention. Papers from the recent OECD conference on 'policy evaluation, innovation and technology' reflect current thinking. There is wide agreement that there is no universally applicable methodology—the choice should depend on the particular case in hand, and should preferably incorporate several approaches.[91]

Overall, therefore, an incremental approach to policy development and evaluation is called for: retaining mechanisms which work; discarding those which do not; and exploring and evaluating new options. Innovation, experimentation and evaluation are key words for the future.

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